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PRINCIPLES AND PROBLEMS OF FISH CULTURE IN PONDS

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FISH as living animals have essentially the same general requirements for growth and propagation as poultry or pigs. As animals living in water, however, they present their needs to us in a so much more obscure way that our problem in providing the proper conditions is relatively complex. We have to meet most of the requirements for successful rearing of fish by very indirect means, and in so doing we have to be guided by a knowledge of general principles and the application of common sense, rather than by any explicit rules.

The ordinary needs of fish, flesh or fowl are: air, water, food, cleanliness, exercise, shade, protection of adults and young from enemies and disease, some control of numbers in proportion to available space, proper conditions for breeding, and care of young. Looking at these requirements severally, we are at once confronted with a striking point of difference between fowl culture and fish culture. *Air*, or more strictly *oxygen*, is freely supplied by nature to animals. With the fish the oxygen problem is paramount, and the fish-farmer must give first thought to the maintenance of a favorable oxygen supply in his pond. Without food the fish would live for days or weeks; without oxygen, it would suffocate in a few hours.

OXYGEN

Here is an excellent illustration of the fact that many of the requirements of fish are supplied by indirect means. Before we can proceed intelligently, we must know how the fish gets the oxygen necessary for its existence, that is to say, by what processes the oxygen supply is maintained in a natural body of water. This is one of our problems in its broad aspect.

Two processes are continually depleting the oxygen supply: The respiration of animals and the decomposition of various materials. In warm weather, too, the water will hold less oxygen, and it is accordingly the more necessary that the supply of oxygen shall then be added to continuously and abundantly.

How is the supply of oxygen maintained in a body of water? There are two principal means, one of which takes care of itself, but which is not entirely adequate for the purpose in small bodies of water.

First we are concerned with the interchange of gases between the surface of the water and the air. Birge has aptly employed the term "respiration of lakes," suggesting that the lake or pond breathes through its surface. He and others have shown how the oxygen supply thus derived is distributed through the body of the lake, and how this distribution is affected by temperature, seasons, winds and other factors.

As regards the propagation and rearing of fishes in self-contained ponds, we are led at once to certain very practical questions. What should be the size, the form, the depth and the relative proportion of deep and shallow waters in the several units of our pond system, or of our single pond if there can be but one? Obviously, for a wintering pond we must provide for storage of oxygen to carry over the winter; but in spring, the season of renewed activity, spawning, and the beginning of life for a new generation, the deep winter pond, now depleted of oxygen, proves ill-adapted for quick recuperation, since the warmer surface waters fail to carry the absorbed oxygen to the bottom. This is the season when the natural ponds and streams are accustomed to broaden their margins and flow out over the surrounding lands, and most of the fish in spawning activity are observed to follow the waters outward and to deposit their eggs in places more or less removed from the customary banks of the stream or pond. They find inducement to this outward migration, perhaps, in the warmer temperatures prevailing in the shallow overflow waters, or, perhaps, in the better conditions of oxygenation which may prevail at least temporarily.

Since it is being attempted to suggest rather than to outline problems, it may be in place to mention without comment two unrelated, but very interesting, facts. It is in the middle or late spring that the Bureau of Fisheries expects and receives the most numerous reports of unexplained mortalities of fishes in closely confined lakes. The other interesting fact is this: For two years, at our Fairport station, the effort to get the buffalo fish to spawn in artificial ponds failed. Last year, Mr. A. F. Shira, the director of the station, made the experiment of causing the pond to flow out gradually over a considerable area of ground just as the temperatures were developing when



Part of a group of ponds for fish-culture experimental work, at the United States Fisheries Biological Station, Fairport, Ia.

spawning could be expected. The buffalo fish acted just as they do in nature; they moved out into the shallow waters and spawned—doubtless the first buffalo fish to spawn in controlled ponds. Whether temperature or oxygen supply, or both, or something else is responsible for phenomena such as these, it is evident that the fish-culturist must look to the student of the physical conditions of enclosed waters for guidance in the construction and the control of ponds.

Just as the trees and the small plants and the grass are continually breaking up noxious gases in the air and replenishing the supply of oxygen, so in the water the submerged vegetation plays an important part in maintaining the oxygen supply for fish. In fact, they are probably the principal dependence for oxygen in ordinary fish ponds. In a very large lake where there are high waves and pronounced wind-driven currents, rolling movements, and upheavals, the vegetation plays a less part. The smaller the pond, however, the more essential are the submerged plants. Plants serve another useful purpose in taking care of the noxious carbon dioxide which is given off by animals in breathing and which is formed by the processes of decomposition.

In selecting plants for the pond for the purpose of oxygenation, it must be kept in mind that plants do not possess this function except in the presence of sunlight. The large lily pads which are so esthetically pleasing, but which, being at the surface, can contribute little to the oxygen supply of the water,

form a deep shade that must diminish the oxygen-producing capacity of other plants living in the water beneath. It is evident that submerged vegetation is wanted and preference may be given to those plants having an abundant growth of narrow leaves, or to those with foliage so finely divided as to be needle-formed or brush-like. Consideration must be given, too, to the species which remain green during the winter or which are the earliest to give rise to new growth in the spring, so that there may be the most effective production of oxygen at a time when it is so important to the breeding fishes, and when the surface absorption of oxygen is normally less adequate.

Here, then, is a problem which has scarcely been attacked. What species of plants are the most effective oxygenators, under different conditions and at different seasons? The experienced and observant fish-culturist has somewhat definite ideas, and his judgment in the matter is very valuable, but I think that very little has been done in the way of experimental determination of the questions just stated. We ought to know, as precisely as we can, the relative oxygenating values of the different species of aquatic plants—for wintering ponds, for spawning ponds, and for rearing ponds.

FOOD SUPPLY

The fish must have food and, under ordinary conditions of fish-culture, the food naturally produced in and about the pond is the principal dependence. Obviously, the productiveness of a pond in fish is directly limited by its productiveness in food;



An Experimental Pond, maintained under the conditions of a farm fish pond.

hence, fish-culturists often say that the whole problem of fish culture is one of food supply. It may well be so, since this is not a single problem, but a complex of problems.

Biologically speaking, the food problem starts with the plants, as the source from which, or through which, all animal food must come. Plants form the basis of food supply—large plants or microscopic plants, green plants or dead plants, or the finely divided plant remains constituting the detritus. To what extent do plants, living or dead, enter directly into the food of fishes? I venture to say that we know yet very little of this. Only a few years ago, the forage value of plants was considered insignificant. Yet, very recently, an investigator associated with our Bureau, Dr. A. S. Pearse, of the University of Wisconsin, has prepared for publication a report of the food of 32 species of fish from lakes in Wisconsin, and, from one of his tables, it can be found that, with 23 species, plant remains or algae constituted an appreciable portion (one per cent. or more) of the stomach contents, ranging from 1 per cent. to 25½ per cent. If we include silt and débris (probably plant material principally), 25 of the 32 species were plant feeders, and the ratio of such food to the total ranges from 1 to 40 per cent. Other uncompleted investigations of the bureau indicate that vegetable detritus constitutes a substantial, or perhaps the principal, element of diet for fresh-water mussels and for the young buffalo fishes. This is certainly true for many insect larvæ, and other small animals.

Undoubtedly, the direct food value of vegetation to pond fishes, especially to the young, is not inconsiderable; but even more significant is the part which this form of food plays in an indirect way. Generally speaking, as the fishes become older and larger (this is not true of all species, of course), they seek larger and more active prey, entomostraca are passed over for small insect larvæ, amphipods, small snails, etc., these in turn give place to larger insect larvæ, crawfishes and small fishes, and finally, larger fishes and frogs may become the special prey of the "big-game hunters" among the fish. But all the multitudinous members of this complex community of hunters and hunted derive their origin from plant matter. Now, one phase of this general problem of the relation of plants to food supply to which it is desired to direct attention is this: We have very little information as to the relative food values of the different species of plants. Undoubtedly, some species of plants are better forage plants than others. Dr. Emmaline

Moore, of Vassar College, and quite recently a special investigator for the Bureau, has already given us some valuable information about this, and I may be permitted to emphasize the point that, as her investigations show, plants of one species may be foraged upon, while those of a closely related species are left untouched. Presumably, too, some plants, when dead and disintegrated, give rise to a more palatable or nutritious detritus than others; of this we know little, if anything.

These questions of the relative values of plants, viewed either as oxygenators or as food makers, are not of theoretical or scientific interest only. This can be made clearer from an analogy. A stock farmer may have no interest whatever in plants as plants. Nevertheless, he sows alfalfa under certain conditions and burr-clover under others; he knows when and where he wants to plant red clover, and he knows that he never wants to plant sweet clover. All of these legumes are fairly closely related, yet the grower of stock has learned to discriminate between them, to use each to best advantage, or to let them alone, as his purpose may require. The grower of fishes, on the other hand, lets grow what will, practically speaking—and who can now advise him intelligently?

Our problem does not stop with the plants—it only begins there, biologically speaking. Small crustacea, insect larvæ, and molluscs feed upon plants or plant remains, and then upon each other. The problem becomes complex and peculiarly ecological, but its solution may be approached very directly. Here is an insect larva which feeds upon certain things and is preyed upon by certain other forms: it attacks and destroys small fishes and is itself devoured by larger fishes; it feeds upon materials which the fish that we wish to foster can not directly consume, thus adding material to the fish's food supply, while it competes with the fish for other forms and so diminishes the food supply; it destroys certain enemies of fishes, but who knows if it harbors some injurious parasite of fishes? The significance of this larva, and it is not altogether an imaginary one, is evidently not to be appraised as the result of casual observation. A great deal of data must be accumulated, the points of contact searched out in various directions, the evidence carefully analyzed, checked by experiment if possible, and weighed with sound judgment before a just conclusion is reached. Common sense will make the final ruling, but it will be common sense seated upon a secure bench of scientific observation and experiment. It would be an excellent thing for

fish culture if one after another of the typical inhabitants of a pond could be taken up for systematic study along such lines as have been suggested.

Since this paper must be kept within reasonable limits and as the ecological rather than the biochemic aspects of fish-cultural problems are primarily in mind, the important subject of the artificial feeding of fishes in ponds must be passed over at this time. More nearly ecological is the question of the fertilization of ponds—the adding to the water of organic or inorganic substances, so as to promote an abundant growth of desirable aquatic organisms, without impairment of the conditions of existence for fish. In this connection, I will merely hint at two very important subjects; that is, the character and composition of the bottom soils and the chemical composition of the water itself. We know that plants and animals have definite chemical requirements, and the requisite substances must come, directly or indirectly, from the soil or from the water. We strongly suspect, at least, that certain chemicals have subtle but significant physiological effects, favorable or unfavorable, upon the growth of aquatic plants and animals—effects that can be discovered not so readily by inference from analysis, as by experimental determination.

So far, we have kept strictly within the confines of the pond itself, but the ecological problems of fish culture extend well beyond the reach even of the highest waves that wash the margins. The sloping banks, the green sward, the meadows beyond, do not these contribute to the food supply of the pond? No one can be doubtful of this after walking around a pond, and noting the small frogs that leap from the banks to be snapped in by a hungry bass, or observing the grasshoppers and crickets resting on the lotus leaves or in the stems of *Persicaria* or of cattails, or watching the dragonflies and mosquitoes and dozens of other insects that pass from bush or grass to pond and back again (if luck is with them). Read the reports of stomach examinations by Forbes and others, and note the extent to which non-aquatic insects and other animals enter into the food of fishes. Mr. H. W. Clark, of the Bureau of Fisheries, tells of trout feeding upon masses of woolly plant lice as fast as they fell from overhanging alders. Professor C. B. Wilson, while working at the Fairport Laboratory, finds a certain dragonfly that, like others, through its larvæ supplies food to fish, but that almost invariably completed its metamorphosis on a hillside slightly removed from the pond, although in order

to arrive at this chosen environment after emerging from the pond, it was obliged to cross a dusty road. Professor J. M. Bates writes in *Science* of serious losses of fish in Pine Creek, Nebraska, caused apparently by feeding upon rose chafers dropping from overhanging willows. These are merely typical illustrations showing some of the various ways in which the land environment affects the fish life within the pond.

Doubtless, in due time fish farmers can be given definite and helpful advice, not only about the maintenance of a suitable environment in the pond, but also regarding the provision of a proper environment about the pond.

ASSOCIATION OF SPECIES

The judicious association of fishes within the pond is, perhaps, one of the most important questions of fish culture. To one who does not consider carefully the conditions of life in ponds, it may seem, offhand, that the only proper plan is one fish to the pond, yet, in all probability, this is rarely the practical plan of action. By associating two or more species of fish in the same pond, we expect to experience benefits in two directions: first—utilize the available space and food to best advantage, and, second—get the best results from any one given species.

There is nothing new in the idea that the appropriate association of species is for the best interest of the fish it is primarily desired to cultivate. An old and quaint, but very practical, book on the culture of the carp, published more than three quarters of a century ago, advises us to introduce with every 200 brood carp, 20 brood tench and 20 brood jack (pike). We can accept the author's explanation of the service of the pike, which is to check the increase (in numbers) of the carp, though we may be skeptical of the function ascribed to the tench, or "doctor fish," namely, to "act medicinally to other fish, by rubbing against them when wounded or sick."

Two chief principles which should guide us in determining the desirable combinations of fish are these. First, that the associated fish should not too severely compete with each other for food; second, that, under certain conditions at least, one of the groups of fishes should prey upon the others to such an extent as to prevent an excessive increase in numbers.

It would, beyond doubt, astonish a stock farmer to be advised to introduced a wolf into the sheep-fold; but what else should he do if he had no other practicable means of preventing his sheep from multiplying in numbers until the pasturage

could no longer support them? It seems to be true that a new pond or lake often produces within a few years fish of particularly large size, and that after a while the fish became much more numerous, but much smaller in size. This is not invariably so, of course; it depends upon the conditions of stocking, but it is easy to see how this may come about. Given at first a reasonably abundant supply of food and a small number of fish, the fish, naturally, thrive and attain rapidly to a large size. The strong healthy fish reproduce successfully and the abundant generations of young, unless soon decimated by enemies, prey so exhaustively upon the available food as even to prevent its growth in formerly normal luxuriance. The introduction, then, by natural or artificial means, of a small number of rapacious fish may lead to such a reduction in the numbers of fish, and such a consequent change in the conditions of competition as to serve the best interests of each and every species within the pond. This is why the German carp growers put pike into the carp ponds.

The control of numbers is an essential condition of success in agriculture, husbandry, or fish culture; but where fish are being reared in ponds it is usually very difficult, if at all possible, to accomplish this end by direct means. Even if the pond is so devised that it may be drained, one can not always draw the pond after each brood is hatched, and to draw the pond may also entail a loss of valuable food supply carried out with the discharge of water.

Unless it be to provide variety, there can be no good purpose served by associating species which have identical feeding habits, and which, therefore, merely compete with one another. If, however, one can group fishes of principally insectivorous with others of principally vegetational diet, it is, obviously to be expected that the pond will yield more fish per acre than if only one half of the existing supply of food could be availed of. One may often, too, wish to introduce a smaller species, which will serve as food for a larger kind that is especially desired.

While the principles of association of fish species which have been outlined may seem almost too obvious to justify discussion, it is remarkable to what an extent they are violated in fact or in intention by persons of high intelligence in all other matters. Every possible species of Salmonidæ is desired in a particular lake. An organization of men, successful in their ordinary pursuits, will want to pour into a pet pond unlimited numbers of bass, pike, pike perch and perch. If a lake frequented for sport fishing is found to contain innumerable small

crappie, the plea is for more crappie, on the fatuous assumption that "new blood" is all that is required to make the fish grow large.

The problems of appropriate associations are interesting and very important. Their solution may be attacked most directly by experiment, but also indirectly by studies of feeding habits and of associations in nature. I hope that I do not give an unduly unfavorable impression of the progress of fish cultural science, when I say that we know very little on the subject of proper association. If you wish to produce the greatest quantity of large-mouth bass per acre, what species of fish would you associate with the bass to serve as food for it—or would you leave the bass to itself and trust to cannibalism for the control of numbers? Apply the same question, if you wish, to other species; but who will now supply the answers based not upon opinion, but upon the sure footing of experimental determination?

In concluding, it seems to me that an apology may be due to the readers of *THE SCIENTIFIC MONTHLY* for presenting a paper which contains so little that is original, and which makes no pretense of adding to the sum total of knowledge. The purpose has been merely to indicate, from one incomplete point of view, a common meeting ground for the fish culturist and the ecologist, the zoologist and the botanist. If this shall lead, in any way, to more frequent meetings upon that ground, the effort of the writer and the time of the reader will not have been wasted.